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(54) Title: METHOD AND APPARATUS FOR DETERMINING THE CONDITION OF A ROLLING BEARING

(57) Abstract

In a method and an apparatus for determining the condition, primarily changes in geometry, of a rolling bearing having a roller cage with rolling elements which are adapted to roll on the races of two thus relatively movable parts, the displacement of the roller cage relative to one of the two parts is sensed simultaneously as the displacement of the ther movable part relative to one of the two relatively movable parts or the roller cage is sensed, and the sizes of the tw sensed displacements for one and the same time are determined. The mutual relation between the sizes determined is compared with a reference value for the relation, whereupon the condition of the bearing is indicated in dependence on the result f the comparison. A monitoring means for rolling bearings includes a generator for supplying power to the electronic devices and circuitry of the means, which generator is driven by relatively movable parts of the bearing and preferably combined with a chargeable battery, a detecting device for detecting the condition of the rolling bearing, an indicating device for indicating the detected condition, and an adjusting device for adjusting the monitoring means at the mounting thereof.

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# METHOD AND APPARATUS FOR DETERMINING THE CONDITION OF A ROLLING BEARING

This invention relates to a method of determining the condition, primarily changes in geometry, of a rolling bearing having rolling elements, preferably with a roller cage, which rolling elements are adapted to roll on the races of two thus relatively movable parts. The invention also relates to an apparatus for realizing this method, and a rolling bearing monitoring means comprised in said apparatus.

The need of monitoring and controlling various forms of rolling bearings increases in step with the increased degree of automatization in industry. Considering the negative effects in terms of operation and cost that may be caused by faults in rolling bearings, it is readily realized that great profits can be achieved by suitable monitoring measures.

Several attempts have been made to provide automatic monitoring of bearings in operation. Thus, there have been suggested both simple methods, such as listening, and relatively sophisticated electronic measuring methods. However, no generally useful method would seem to have been found.

To satisfy the requirements outlined above the present invention now suggests, as a fundamental solution, the provision of a self-sufficient monitoring means which may be either a separate unit or integrated with a bearing. This monitoring means includes a small generator for supplying the electronic circuitry and devices of the assembly with power, said generator being driven by the relatively movably mounted parts and preferably combined with a chargeable battery for maintaining the power supply also when said parts are stationary; a detecting device for detecting the condition of the bearing, primarily changes of geometry which may occur in

the movably mounted part; an indicating device for indicating the condition of the bearing, suitably by way of a two-position indication; and an adjusting device which permits adjusting and zero setting of the monitoring means at the mounting thereof.

The monitoring means can be realized with the use of inductive, capacitive, optical, resistive, mechanical or hydraulic transducers.

In the inductive case, permanent magnets mounted for example on a rotatable shaft can be utilized in combination with fixedly arranged Hall elements. This embodiment permits controlling the bearing statically and dynamically, is rather insensitive to non-magnetic soiling and can give a high exactitude considering that sensitive component parts are available.

In the capacitive case, capacitor foils can be arranged on an outer ring while the shaft proper can be exploited as an opposite capacitor foil. Static as well as dynamic deviations can be detected in this design. The solution is structurally simple and provides an energy saving detection. Air or grease can be used as dielectric.

In the optical case, use can be made for example of a light transmitter which emits a beam towards the rotating shaft in a radial plane, in combination with say a CCD element which may be of the linear or matrix type. In the latter embodiment, it will be possible also to obtain information of an axial play, if any. This solution gives a high exactitude, is relatively simple to adjust and also relatively insensitive to impurities. It permits monitoring the bearing both statically and dynamically. Component parts, however, are relatively expensive and energy consuming.

In the resistive case, for example an embodiment using conductive plastics as a pressure transducer is conceivable. This monitoring means can be designed as a non-loaded rolling bearing, in which resistive trans-

ducers of flexible plastic are arranged in a flexible suspension ring for the outer ring of the non-loaded bearing. This embodiment permits both static and dynamic monitoring, is simple to manufacture, relatively energy-saving and can be conceived hermetically encapsulated. The means is also self-centering and as a consequence self-adjusting. Axial play can also be detected with the use of a resistive detecting device of this kind.

In the mechanical case, radial play of a rotatable shaft can be detected by means of a detector biased against the shaft and being capable of reacting to an extremely small mechanical displacement so as to release a mechanical indicating device when said displacement exceeds a predetermined value. In this mechanical embodiment, the detecting device is simple to mount, simple to adjust and requires no electric power generator.

In the hydraulic case, use is made of a hydraulic fluid passage surrounding the shaft and optionally divided into several part passages. The pressure of the hydraulic fluid can be sensed at one or more points by pressure sensors, and at vibrations in the shaft variations arise in the signals emitted by the pressure sensor or sensors. This embodiment requires no adjustment whatsoever, places low requirements on the precision of gaps and the like, and is energy saving. For static monitoring said passage has to be divided into several parts, and an adjustment will also be necessary.

In combination with the above-mentioned detecting devices, the monitoring means according to the invention requires an indicating device which may be of the electric type and make use of say liquid crystals, light emitting diodes or light guides. A purely mechanical indication is also possible, particularly in the above-described case of mechanical detection. The indicating device is preferably designed as a merely locally indicating device, i.e. entirely built into the monitoring

means, but it is of course possible to connect the indicating device to a central common to several monitoring means.

The indicating device preferred in connection with the monitoring means, however, is of an entirely novel design which bases its detection on a determination of the condition of the rolling bearing, in which changes in bearing geometry are exploited.

Rolling bearings can be compared to planetary gearings in which the paths of meshing gears have been replaced by rolling element races. In a gearing the relative rotation of the parts always takes place under the control of gear teeth and the transmission ratio is thus constant. In a rolling bearing, the transmission ratio is dependent upon the dimensions of the parts of the bearing and the sliding of the rolling element races at the contact surfaces. Any change in the geometry of the rolling element races thus also results in a change of the transmission ratio between the parts of the bearing.

On dimensional changes in the component parts of the bearing because of deformations, wear, temperature changes, load changes or lubrication changes, the relations between the relative transmission ratio or angular rotation of the parts of the bearing will thus change. These dimensional changes, such as changes in radius of a thousandth of a millimetre, normally are difficult to detect in operation, for which reason this invention instead makes use of the way in which these dimensional changes reflect on the circumferences of the bearing parts, i.e. use is made of the changing relations between the lengths of the orbits. By this procedure, the desirable exactitude is readily attained since the changing displacements of the rolling element races relative to each other because of dimensional changes increase with the increasing number of revolutions.

According to the invention, it is therefore desirable that the speed relation between the bearing parts rotat-

ing about the centre of the bearing, i.e. the outer ring, the roller cage and the inner ring, is measured. One of said bearing parts is considered as stationary even if all bearing parts actually may rotate. The movements of the outer and inner rings in most cases can be measured from outside. The detection of the angular rotation of the bearing parts should preferably be made without contact and digitally with great resolution per turn. The rotation of the roller cage can be detected with the aid of the rolling elements when these go past a measuring zone. The greater the number of rolling elements contained in the rolling bearing the greater the resolution. As the rolling elements generate an impact each time they enter a loading zone, it is possible to "listen to" or sense said impact at the passage of the rolling elements and thereby to indicate the speed of the roller cage.

Arising vibration and sound frequencies are in a machine speed relation to the angular speeds of the rotating bearing parts. The angular speeds in turn are in a mutual relation to each other by their geometric dimensions.

The detection of the movements of the roller cage can thus take place by a count of passing rolling elements, say by radially transilluminating the bearing housing, the bearing and the seals with a gamma ray.

A further possibility of detecting the movement of the roller cage is to utilize one or more inductive transducers which are so mounted that a pulse train generated by the rolling elements is obtained, possibly together with a separate pulse train for the rotation of the outer or inner ring. In the latter case it is also suitable to build all electronic devices and circuitry as a unit into the bearing housing together with the power supply unit and the indicating unit.

As mentioned in the foregoing, a rolling bearing can be compared to a planetary gearing without gear teeth. There does not occur any engagement between the

races which engage each other only in the loaded parts of the bearing. Sliding and other faults may arise in the contact surfaces and the rolling elements can advance by leaps because of irregularities or vibrations. The rolling distances therefore will not be exactly the same as if an engagement by gear teeth had taken place.

A fresh bearing which is correctly mounted, loaded and greased, like the planetary gearing, has a transmission ratio theoretically dependent on the radii of the component parts. As it is necessary to indicate differences in radius of thousandths of a millimeter, one has to take into account the deformation of the various parts after mounting, loading and temperature increase. Thus, the geometry of the bearing is variable. The machine elements are elastic and moreover the geometric measures are influenced by the grease film.

By counting a definite number of parts of a revolution on one of the bearing rings and, during the same time, counting the number of parts of a revolution on the roller cage, it is possible to determine the current transmission ratio of the bearing. The new value of this ratio should coincide with the theoretically calculated one, if the bearing is correctly mounted. This thus gives the possibility of a simple mounting control.

The permissible differences in the transmission ratio have to be judged from case to case and shall permit being readily programmed. By taking the temperature into account it is possible to judge whether the bearing is worn, too much loaded or enlarged by temperature.

The races of the outer ring, the rolling elements and the inner ring theoretically always run equally far. If the radius of any one of them changes or if any one of them slides or jumps relative to one another, the relation between the displacements of the bearing parts or the rotation angles change and so does the transmission ratio.

Different bearing dimensions and bearing types have

different transmission ratios; application and actual conditions must also be taken into account. To judge changes of conditions in bearings attention therefore also has to be paid to matters that do not result from deformation and wear. This can be done with the aid of a computer which by means of measured values derived from the speed measurements and from say temperature, vibration and/or sound measurements, can distinguish between different reasons for changes of conditions in a bearing.

For example, a higher temperature inside the bearing than outside it, implies frictional losses. The temperature difference is coupled to the speed and the load of the bearing. The more worn the bearing, the coarser the bearing surfaces and as a result the temperature can increase even if the load does not.

To take temperature differences into account, the bearing housing can be provided with a through temperature measuring nipple which consists of a heat insulating tube and a heat conductive internal rod in said tube, the lower part of said rod connecting onto the stationary, temperature monitored bearing ring. The temperature measuring head as well as sound and vibration measuring heads can be connected to the upper part of said rod.

For vibration and sound measurement, for example a piezo electric transducer can be connected to a metal nipple screwed into the bearing housing. The closer this nipple is to the rolling elements in the load zone, the better. The vibration and sound frequencies can be compared with the speed of the bearing and sorted into the frequencies expected on the basis of the transmission ratio. If the resulting frequency derives from the rolling element pulse train and is distinct no transducer is necessary within the bearing to indicate rolling elements.

In an evaluating unit, for example the transmission ratio and the tolerated variation therein can be programm-

ed. In the same way the highest permissible temperature difference and quickest temperature rise can be programmed. Permissible vibration frequencies and levels can be programmed in the same way.

The power generator of the monitoring means according to the invention may comprise a stationary induction coil connected to a central unit. In this case, the rotating machine part/bearing part is provided with one or more fixedly mounted permanent magnets which move past the induction coil. The current pulses generated can charge a chargeable buffer battery and can be utilized at the same time to indicate the number of revolutions or part revolutions of the bearing ring.

The indicating device of the monitoring means may in the simplest case be solely an alarm contact with adjustable alarm level. A light emitting diode on the monitoring means proper can indicate good or poor condition of the rolling bearing. Of course, several alarm levels may be provided.

The monitoring means may for example include two speed transducers, one of which is associated with one bearing ring while the other transducer is associated with the roller cage, transducers for two temperatures, i.e. one transducer in the interior of the bearing and another transducer on the outer side thereof, vibration and sound transducers, and bearing load transducers, i.e. wire strain gauges.

The evaluating unit may be a microcomputer for making calculations and for compilation of measured values.

The parts of the monitoring means can be put together into a unit, but can also be placed separately. Use can be made of a common central unit which can receive and process signals from a great many monitored bearings.

A simpler version of the monitoring means can be placed in a special bearing or bearing housing which also houses the monitored bearing. Then, everything is

collected in one place and the programmed values can be fed into a storage circuit contained in the unit.

The transmission ratio between the inner ring and the roller cage when the outer ring is stationary can be derived as the radius of the double roller cage divided by the radius of the inner ring. When the inner ring is stationary, the transmission ratio between the outer ring and the roller cage can be derived as the radius of the double roller cage divided by the radius of the outer ring. When the roller cage is stationary, the transmission ratio between the inner ring and the outer ring will be the radius of the outer ring divided by the radius of the inner ring, that is the transmission ratio will be the same as if the inner ring had run directly on the outer ring. In this case, the rolling elements only serve as intermediate wheels.

If it is assumed by way of example that the radius of an outer or inner ring in the load zone has been deformed by a thousandth of a millimeter, there is obtained for each revolution an additional shift of about 6 thousandths of a millimeter compared to the state before the deformation. When the bearing then makes a thousand revolutions there will be a shift in the distance transversed of about 6 mm, which in a small bearing may amount to an entire rolling element pitch.

Finally, it should be pointed out that only the absolute speeds and their relations are of importance in the geometric comparison and that the invention is not restricted to rotary bearings, such as radial and thrust bearings, but can be applied also to linear or arched bearing races.

CLAIMS

1. A method of determining the condition, primarily changes in geometry, of a rolling bearing having rolling elements, preferably with a roller cage, which rolling elements are adapted to roll on the races of two thus relatively movable parts, comprising sensing the displacement of the rolling elements relative to one of said two parts, simultaneously sensing the displacement of the other of said two parts relative to said one part or said rolling elements, determining the sizes of the two sensed displacements for one and the same time, comparing the mutual relation between the determined sizes with a reference value for said relation, and indicating the conditions of the bearing in dependence on the result of the comparison.

2. A method as claimed in claim 1 when the two parts are an outer ring and an inner ring, comprising determining the sizes of the displacements as numbers of revolutions about the bearing center, and using the difference or quotient between said revolutions as a comparative value.

3. A method as claimed in claim 1, comprising determining an individual reference value on the basis of the condition of the bearing at the mounting thereof.

4. A method as claimed in any one of claims 1-3, comprising determining the displacement of the rolling elements by detection of the displacement of the roller cage.

5. An apparatus for determining the condition, primarily changes in geometry, of a rolling bearing having a roller cage with rolling elements which are adapted to roll on the races of an inner ring and an outer ring thus rotatable relative thereto, comprising two speed detectors, one detector detecting the speed of the roller cage relative to one of the rings, while the other

detector detects the speed of the other ring relative to said one ring or said roller cage, an evaluating unit for determining the mutual relation between the detected speeds and for comparing it with a reference value for the same relation, and an indicator for indicating the condition of the bearing in dependence on the result of the comparison.

6. An apparatus as claimed in claim 5, wherein one speed detector is a generator which is driven by the relative movement of the inner and outer rings and generates a current pulsating in dependence on the speed.

7. An apparatus as claimed in claim 5, wherein temperature detectors connected to the evaluating unit are adapted to sense the temperature difference between the interior and exterior of the roller bearing.

8. An apparatus as claimed in claim 5, comprising a vibration detector connected to the evaluating unit for sensing vibrations in the bearing.

9. A rolling bearing monitoring means comprising a generator for supplying power to the electronic devices and circuitry of the means, said generator being driven by relatively movable parts of the bearing and preferably combined with a chargeable battery, a detecting device for detecting the condition of the rolling bearing, an indicating device for indicating the condition detected, and an adjusting device for adjusting the monitoring means at the mounting thereof.

10. A monitoring means as claimed in claim 9, wherein the detecting device includes two detectors for detecting the displacement of a roller cage in the rolling bearing relative to one movable part and the displacement of the other movable part relative to said one part or said roller cage.

**AMENDED CLAIMS**
[received by the International Bureau on 28 October 1983 (28.10.83)
original claims 1 to 10 replaced by amended claims 1 to 9]

1. A method of determining the condition, primarily changes in geometry, of a rolling bearing having rolling elements, preferably with a roller cage, which rolling elements are adapted to roll on the races of two thus relatively movable parts, comprising sensing the displacement of the rolling elements relative to one of said two parts, simultaneously sensing the displacement of the other of said two parts relative to said one part or said rolling elements, determining the sizes of the two sensed displacements for one and the same time, comparing the mutual relation between the determined sizes with a reference value for said relation, determining said reference value on the basis of the condition of the bearing at the mounting thereof, and indicating the conditions of the bearing in dependence on the result of the comparison.

2. A method as claimed in claim 1 where the two parts are an outer ring and an inner ring, comprising determining the sizes of the displacements as numbers of revolutions about the bearing center, and using the difference or quotient between said revolutions as a comparative value.

3. A method as claimed in claim 1 or 2, comprising determining the displacement of the rolling elements by detection of the displacement of the roller cage.

4. A rolling bearing monitoring means comprising a generator for supplying power to electronic devices and circuitry of the means, said generator being driven by relatively movable parts of the bearing and preferably combined with a chargeable battery, a detecting device for detecting the condition of the rolling bearing, an indicating device for indicating the condition detected, and an adjusting device for adjusting the monitoring means at the mounting thereof.

5. A monitoring means as claimed in claim 4, wherein the detecting device includes two detectors for detecting the displacement of a roller cage in the rolling bearing relative to one movable part and the displacement of the other movable part relative to said one part or said roller cage.

6. A monitoring means as claimed in claim 5, wherein said movable parts are an inner ring and an outer ring thus rotatable relative thereto, one of said detectors detects the speed of the roller cage relative to one of the rings, while the other detector detects the speed of the other ring relative to said one ring or said roller cage, said detecting device further includes an evaluating unit for determining the mutual relation between the detected speeds and for comparing it with a reference value for the same relation, and said indicating device indicates the condition of the bearing in dependence on the result of the comparison.

7. A Monitoring means as claimed in claim 6, wherein one speed detector is a generator which is driven by the relative movement of the inner and outer rings and generates a current pulsating in dependence on the speed.

8. A monitoring means as claimed in claim 6, wherein temperature detectors connected to the evaluating unit are adapted to sense the temperature difference between the interior and exterior of the roller bearing.

9. A monitoring means as claimed in claim 6, comprising a vibration detector connected to the evaluating unit for sensing vibrations in the bearing.

# INTERNATIONAL SEARCH REPORT

International Application No PCT/SE83/00215

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC 3

G 01 M 13/04, F 16 C 19/52

**II. FIELDS SEARCHED**

Minimum Documentation Searched

| Classification System | Classification Symbols |
|---|---|
| IPC 3 | F 16 C 19/52, 25/00-08, G 01 M 13/00,04, G 05 D 13/64 |
| US Cl | 73:9, 93 |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched

SE, NO, DK, FI classes as above

**III. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category | Citation of Document, with indication, where appropriate, of the relevant passages | Relevant to Claim No. |
|---|---|---|
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| X | DE, A, 1 648 542 (KRENTSCH, BONDARENKO, SURKOW) 27 January 1972 | 1-5 |
| X | DE, A1, 2 845 165 (SPECIALNOE OPYTNOE PROEKTNOE -KONSTRUKTORKSO-TECKNOLOGITSCHESKOE BJURO SIBIRSKOGO UTDELENIJA VSESOJUZNOJ AKADEMII SELSKOCHOZJAJSTUENNYCK NAUK I MENI V.I. LENINA) 7 June 1979 & FR, 2 410 813 JP, 54 091 352 US, 4 213 346 | 1-5 |
| X | DE, C2, 2 947 937 (KOCITSCH J AND BERNDT W) 5 January 1983 | 1-5 |
| A | GB, A, 905 357 (MINIATURE PRECISION BEARINGS INC) | 1-5 |

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**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 1983-08-25 | 1983-08-31 |
| **International Searching Authority** | **Signature of Authorized Officer** |
| Sw dish Patent Office | Per H Cederholm |

International Application No. PCT/SE83/00215

| III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET) | | |
|---|---|---|
| Category* | Citation of Document, [16] with indication, where appropriate, of the relevant passages [17] | Relevant to Claim No [18] |
| A | GB, A, 938 383 (SOC. DE FABRICATION D'INSTRUMENTS D E MESURE) 3 August 1960 | 1-5 |